

THERMAL EMISSION FROM INTERSTELLAR DUST IN AND NEAR THE
PLEIADES

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ABSTRACT

IRAS survey coadds for a $8.7^\circ \times 4.3^\circ$ field near the Pleiades provide evidence for dynamical interaction between the cluster and the surrounding interstellar medium. The far-infrared images show large region of faint emission with bright rims east of the cluster, suggestive of a wake. Images of the far-infrared color temperature and $100\ \mu\text{m}$ optical depth reveal temperature maxima and optical depth minima near the bright cluster stars, as well as a strong optical depth peak at the core of the adjacent CO cloud. Models for thermal dust emission near the stars indicate that most of the apparent optical depth minima near stars are illusory, but also and provide indirect evidence for small scale interaction between the stars and the encroaching dust cloud.

INTRODUCTION

The encounter of the Pleiades star cluster with a small interstellar cloud (Gordon and Arny 1984; Federman and Willson 1984; White 1984a,b; Breger 1986, 1987) has created a laboratory for the investigation of interstellar processes. The Infrared Astronomical Satellite (IRAS) opened new windows to that laboratory, revealing for the first time the distribution of long wavelength radiation emitted by the dust in the familiar optical reflection nebulae. Castelaz, Sellgren, and Werner (1987, CSW) reported on an initial examination of IRAS data for a $2.25^\circ \times 2.25^\circ$ region centered on the cluster. They concluded that the $60\ \mu\text{m}$ and $100\ \mu\text{m}$ data could be understood as thermal emission from typical interstellar grains, whereas the $12\ \mu\text{m}$ and $25\ \mu\text{m}$ data required the action of single-photon excitation of small grains or large molecules.

This paper presents preliminary results from an investigation of new IRAS survey coadds. The data set is a mosaic of eight $2.25^\circ \times 2.25^\circ$ fields, covering $8.7^\circ \times 4.3^\circ$, a much larger region than studied by CSW.

The data have received processing to remove some of the artifacts present in the earlier data and the slope of the zodiacal background, but detectable signatures of the satellite and the data processing remain.

The analysis follows the interpretation of CSW that the 60 μm and 100 μm images primarily represent optically thin thermal emission, and yields images of color temperature, T_c , and 100 μm optical depth, τ , for an assumed dust emissivity varying as λ^{-1} . [Although the derived values of T_c and τ depend on the emissivity law, qualitative characteristics of the images do not.]

LARGE SCALE STRUCTURE

Figure 1 is a contour diagram of the 60 μm surface brightness mosaic. The 100 μm mosaic exhibits the same features. The dominant features of both images are: (1) bright emission to the right of center, at the position of the Pleiades; and (2) the elongated region to the left (east) of the cluster, which exhibits faint emission and a brighter rim. The orientation of this feature is consistent with the east-west alignment of streamers in the Pleiades reflection nebulae (Arny 1977), and appears to be the wake left by the passage of the cluster through the interstellar medium.

The individual subimages in the mosaic received entirely separate treatment in the data processing. Consequently, although the surface brightness mosaics appear nearly seamless, images of far-infrared color temperature and optical depth clearly reveal the subimage boundaries. This circumstance renders difficult further interpretation of the large scale structure at the present time. The bright emission near the cluster, however, is insensitive to small differences in background between subimages.

THE CLUSTER ENVIRONMENT

The maximum surface brightness at both 60 μm and 100 μm occurs at a position south of 23 Tau (Merope), although there are secondary peaks near positions of luminous cluster stars. The images of color temperature and 100 μm optical depth clarify the physical situation.

Figure 2 shows prominent peaks in T_c , up to 46 K, at or near the positions of bright stars, above a broad plateau emission with $T_c \sim 30$ K. This pattern fulfills the expectation that a star cluster embedded in an interstellar dust cloud would yield local temperature maxima within a larger region heated by the collective ultraviolet emission of the cluster stars.

Figure 3 exhibits a strong τ peak that coincides with the core of the small CO cloud southwest of 23 Tau (Federman and Willson 1984; Bally and White 1989), fainter structure to the southwest of the peak that matches the morphology of the CO cloud, and a ridge that details the dust distribution that is roughly outlined by optical polarization data (Breger 1986, 1987).

The figure also exhibits local minima near the positions of the brightest stars,

and a minimum that extends eastward from the cluster core. The latter feature corresponds to the 21-cm "hole" discussed by Gordon and Arny (1984) and confirmed by Breger (1986). Its larger structure is confused by mosaic boundaries, but it suggests that the large scale "hole" present in Figure 1 results primarily from a dearth of dust, not from unusually low dust temperatures.

SMALL SCALE STRUCTURE

Preliminary analysis of these images has included construction of simple models for the thermal emission near several stars, under the assumption that the dust is optically thin both in the infrared and in the ultraviolet, with parameters adjusted to give reasonable representations of the T_c - and τ -profiles within 15' of the star. Results to date include the following.

1. Apparent minima in τ occur at the positions of luminous stars even for uniform layers, as a consequence of the single temperature analysis of the surface brightness ratios.
2. The most luminous Pleiades star, η Tau, lies in a real cavity in the dust distribution that is evident both in T_c and τ .
3. Unless the 100 μ m dust emissivity is unexpectedly large, >0.005 , all the stars examined require unresolved cavities to account for the relatively modest color temperatures observed.

Thus, although apparent τ -minima near the stars must be regarded with caution, the analysis indicates that small scale interactions between the stars and the surrounding interstellar medium do occur. Possible mechanisms for interaction between the stars and the surrounding interstellar medium include ram pressure from stellar winds, the direct influence of radiation pressure, and thermal pressure resulting as the interstellar gas is heated indirectly by starlight.

CONCLUSIONS

1. Far-infrared images of an $8.7^\circ \times 4.3^\circ$ region near the Pleiades provide evidence for a "wake" produced by passage of the cluster through the ambient interstellar medium.
2. Images of the far-infrared color temperature and 100 μ m optical depth in a $2.6^\circ \times 2.6^\circ$ region near the cluster show:
 - a. temperature peaks and optical depth minima near the positions of luminous stars;
 - b. an optical depth peak and fainter structure corresponding to that seen in CO emission, plus more extended features previously inferred from polarization data.

3. Models for the thermal emission near the stars provide indirect evidence for unresolved cavities resulting from dynamical interaction between the stars and the surrounding interstellar medium.
4. The optical depth distribution therefore suggests the presence of both large scale and small scale dynamical interactions between the Pleiades and an interstellar cloud that appears to be encroaching from the western side of the cluster (Arny 1977; Gordon and Arny 1984).

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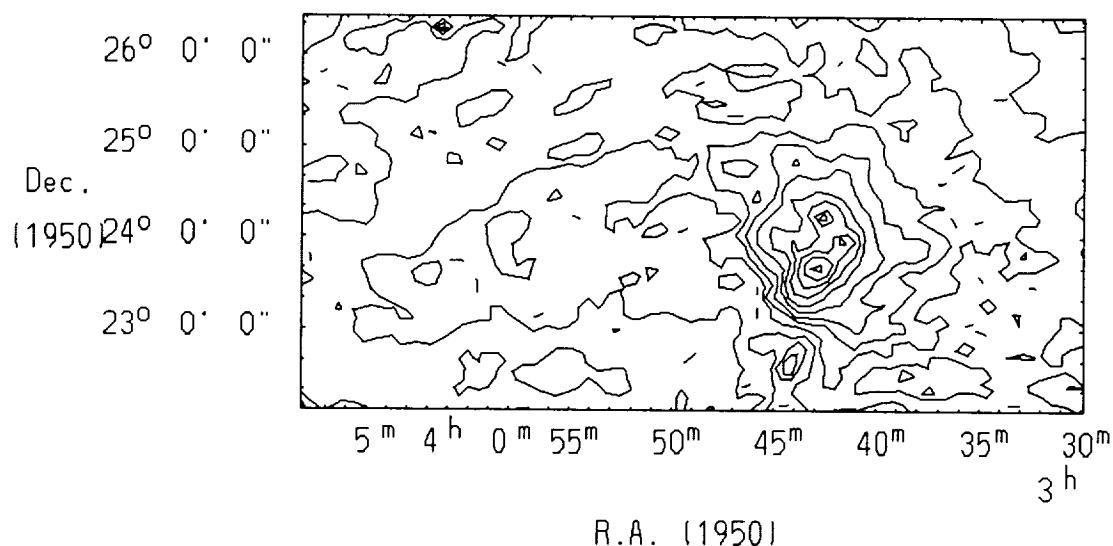


Figure 1. Contour diagram of 60 μ m surface brightness mosaic, which covers $8.7^\circ \times 4.3^\circ$ near the Pleiades. The contour interval is 0.25 dex. The brightest contour represents $\log S_{60} (\text{Jy sr}^{-1}) = 8.0$. The peak value is 8.15.

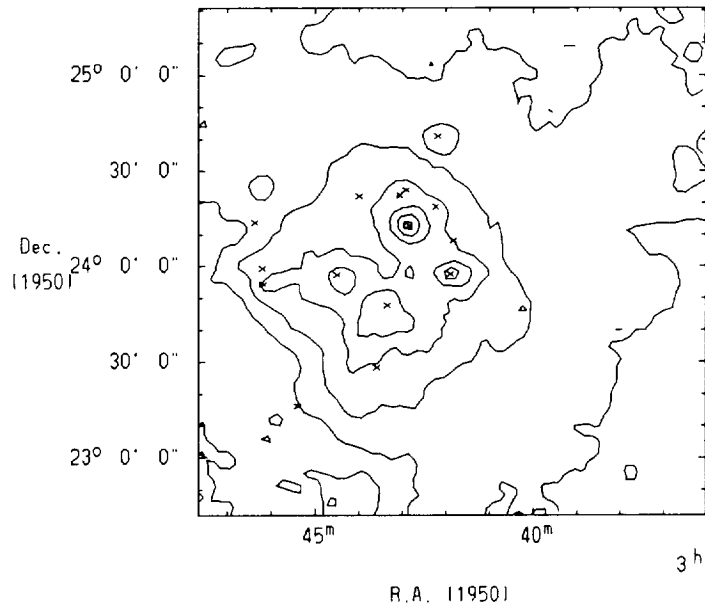


Figure 2. Color temperatures in the immediate vicinity of the Pleiades, derived from the ratio of $60\text{ }\mu\text{m}$ and $100\text{ }\mu\text{m}$ surface brightnesses assuming that the opacity varies as λ^{-1} .

The contour interval is 4 K. The brightest contour represents 44 K, and the peak value is 45.3 K. The crosses represent positions of the most luminous cluster stars.

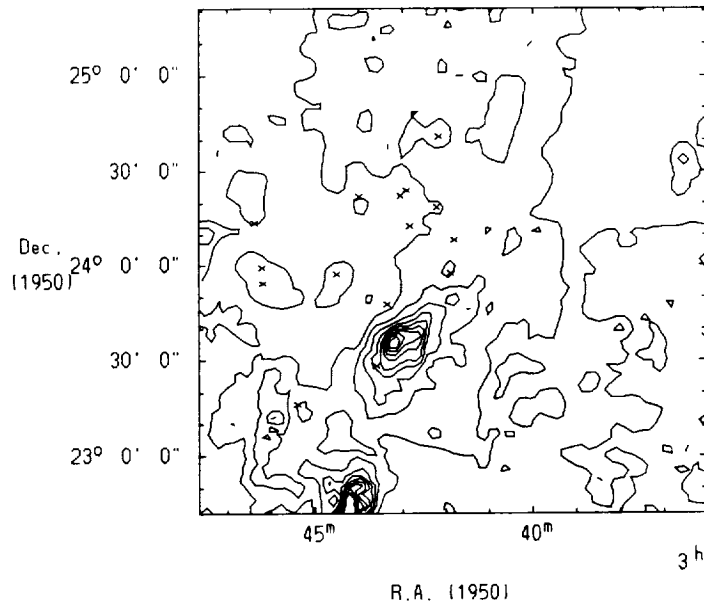


Figure 3. Optical depths derived from the $100\text{ }\mu\text{m}$ surface brightnesses and the color temperatures in Figure 3. The contour interval is 5×10^{-5} . The highest contour represents 6×10^{-4} . The peak value near the cluster is 5.6×10^{-4} . The crosses represent positions of the most luminous cluster stars.

